Evaluating the potential of chemical reanalysis products for air pollution exposure assessment

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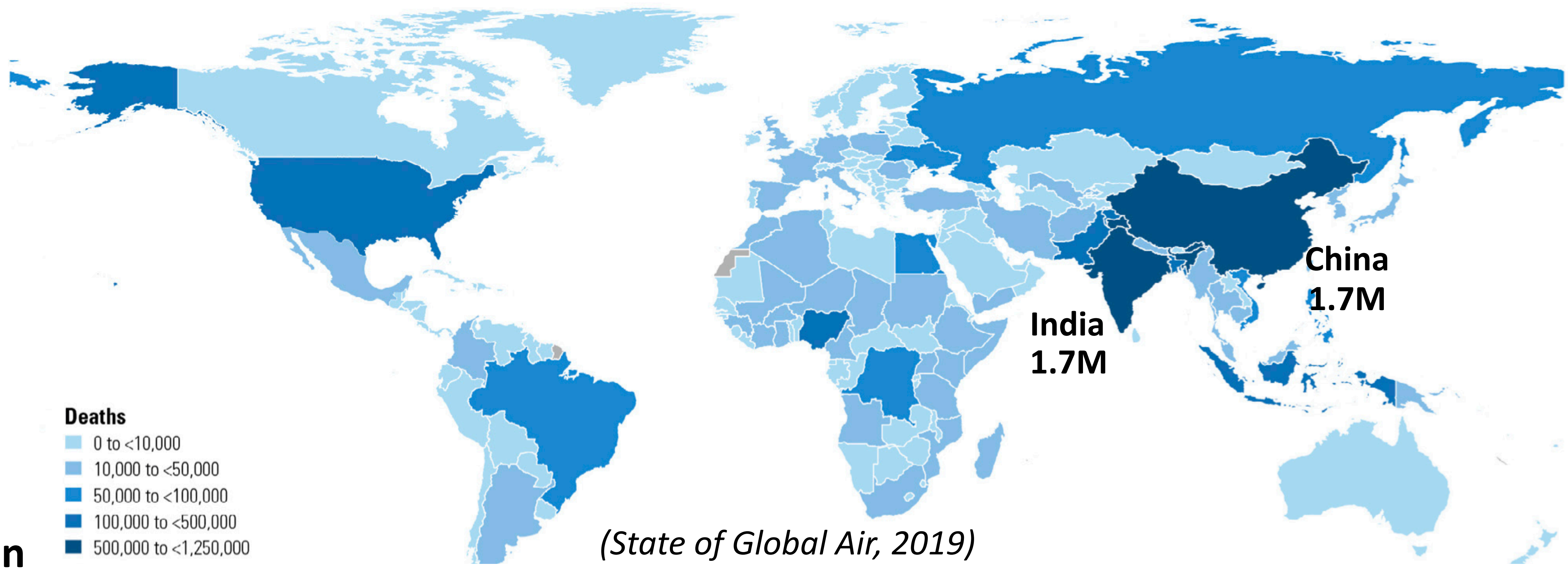
Long-term ozone exposure and mortality

Number of deaths attributable to air pollution (ambient PM2.5, household, and ozone) in 2017



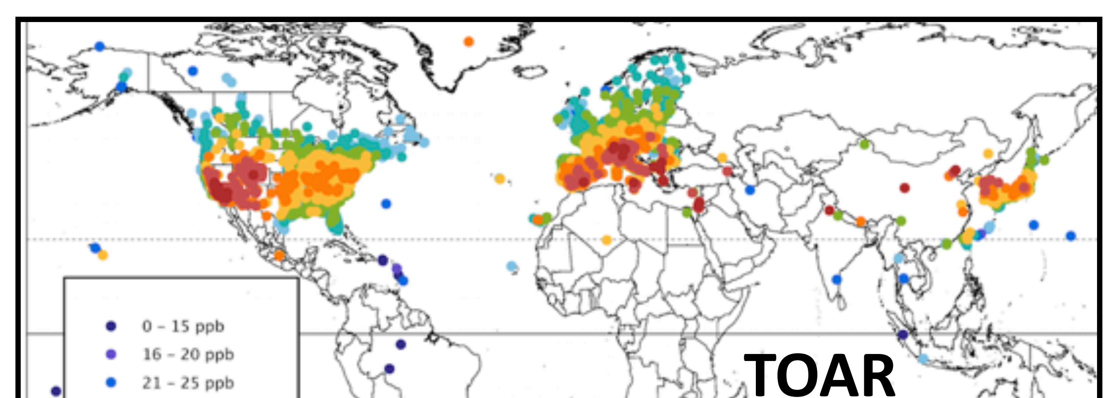
(State of Global Air, 2019)

Air pollution

- is the fifth highest mortality risk factor globally and associated with about 4.9 million deaths (2017)
- reduced about 20 months of our life in average, with significant regional differences
- **<u>Developing countries</u>**: Increased emissions & stronger OPE → increasing risks

The in-situ observing network is clearly insufficient for global health impact assessment (Fleming et al., 2017; Seltzer et al., 2018 for US, Europe, and China)

The regular surface ozone monitoring sites: Roughly only 17% of the global population!



Long-term ozone exposure and mortality

Emissions → **Concentrations** → **Health Impacts**

Chemical transport models

Population, Mortality rate,
Concentration response

Chemical transport models provide global maps but suffer from systematic errors (Silva et al., 2016; Malley et al., 2017, Zhang et al., 2018). Chang et al. (2019) combined multiple models and TOAR observations, but it is still limited by the observing network

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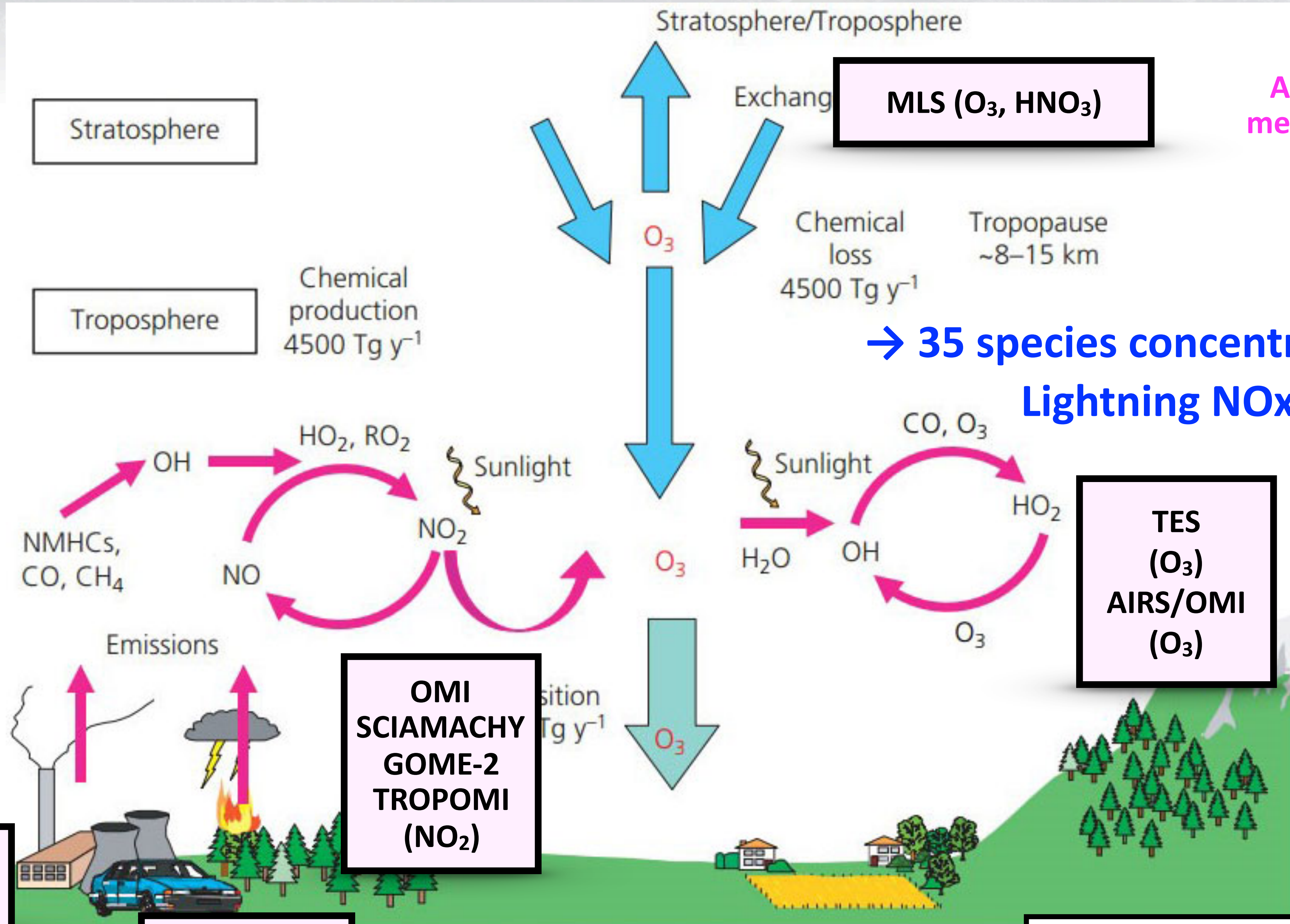
New state-of-the-art chemical data assimilation systems can mitigate these limitations by integrating various observational information with a model

Observations ↓ **Emissions** (IMPROVED) → **Observations** ↓ **Concentrations** (IMPROVED) → **Health Impacts**

Multi-constituent chemical data assimilation

EnKF data assimilation to integrate a suite of measurements from multiple satellite sensors



MLS (O_3, HNO_3)

Assimilated measurements

→ 35 species concentrations + Lightning NOx

TES (O_3) AIRS/OMI (O_3)

OMI SCIAMACHY GOME-2 TROPOMI (NO_2)

MOPITT (CO)

OMI (SO_2)

OMI (HCHO)

→ NOx, CO, SO_2 emissions

→ VOCs emissions (under development)

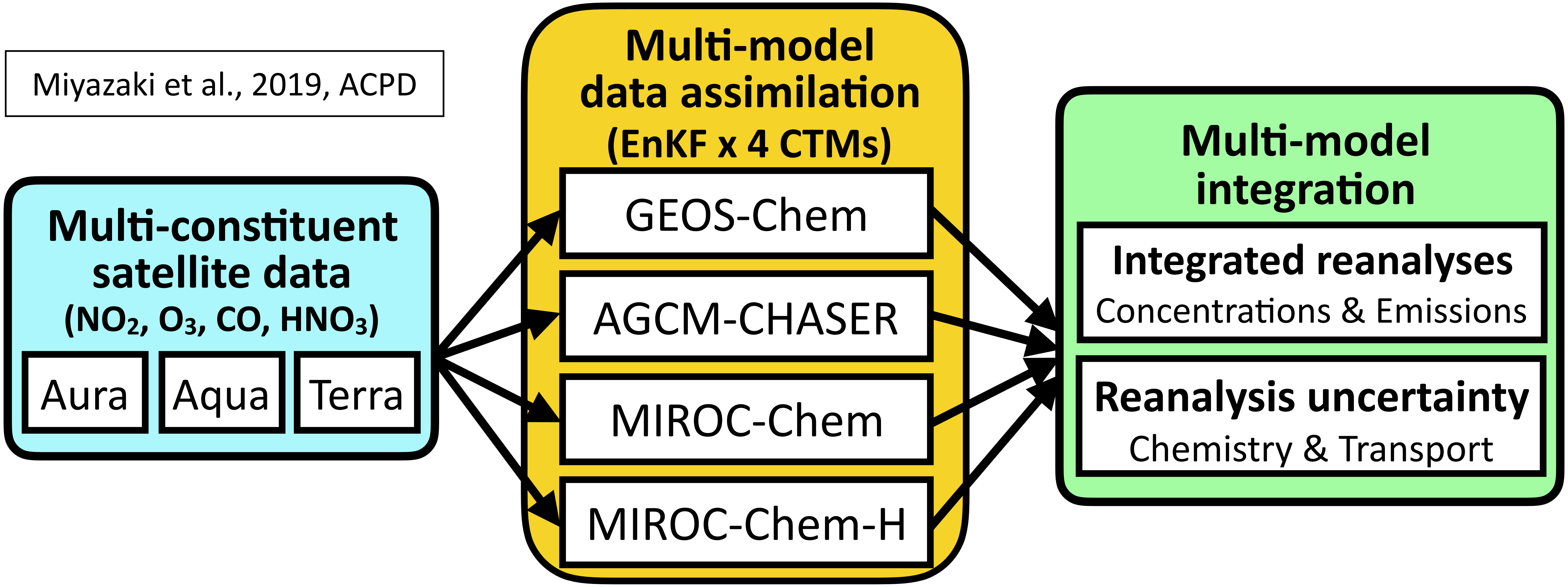
Tropospheric Chemistry Reanalysis (TCR-2)

Multi-model data assimilation integration

Chemical reanalyses provide useful information on exposure estimates and its attributions. Nevertheless, **systematic model errors must be quantified in order to assess their fidelity**

Multi-mOdel Multi-cOnstituent CHEMical data assimilation (MOMO-Chem)

Miyazaki et al., 2019, ACPD



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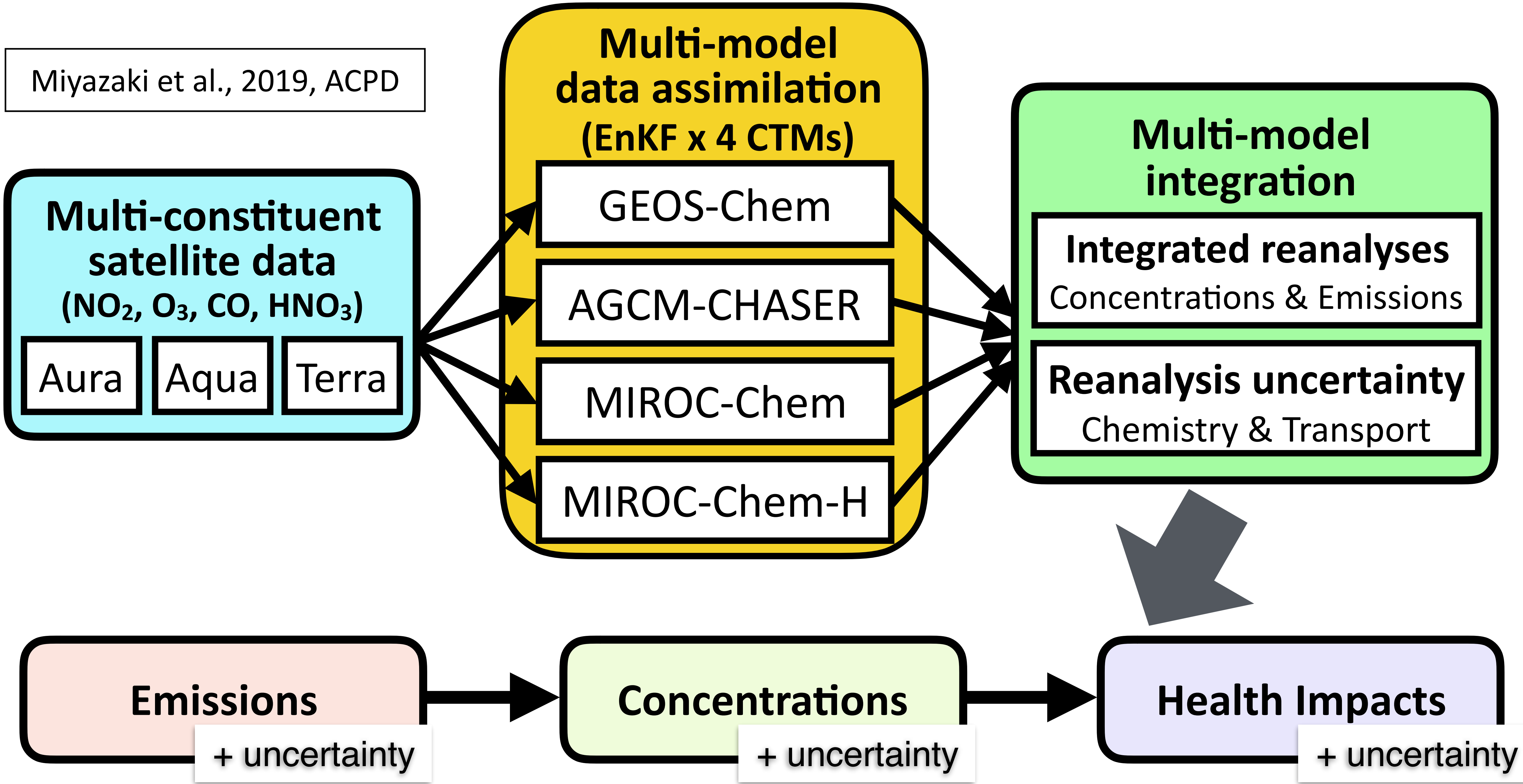
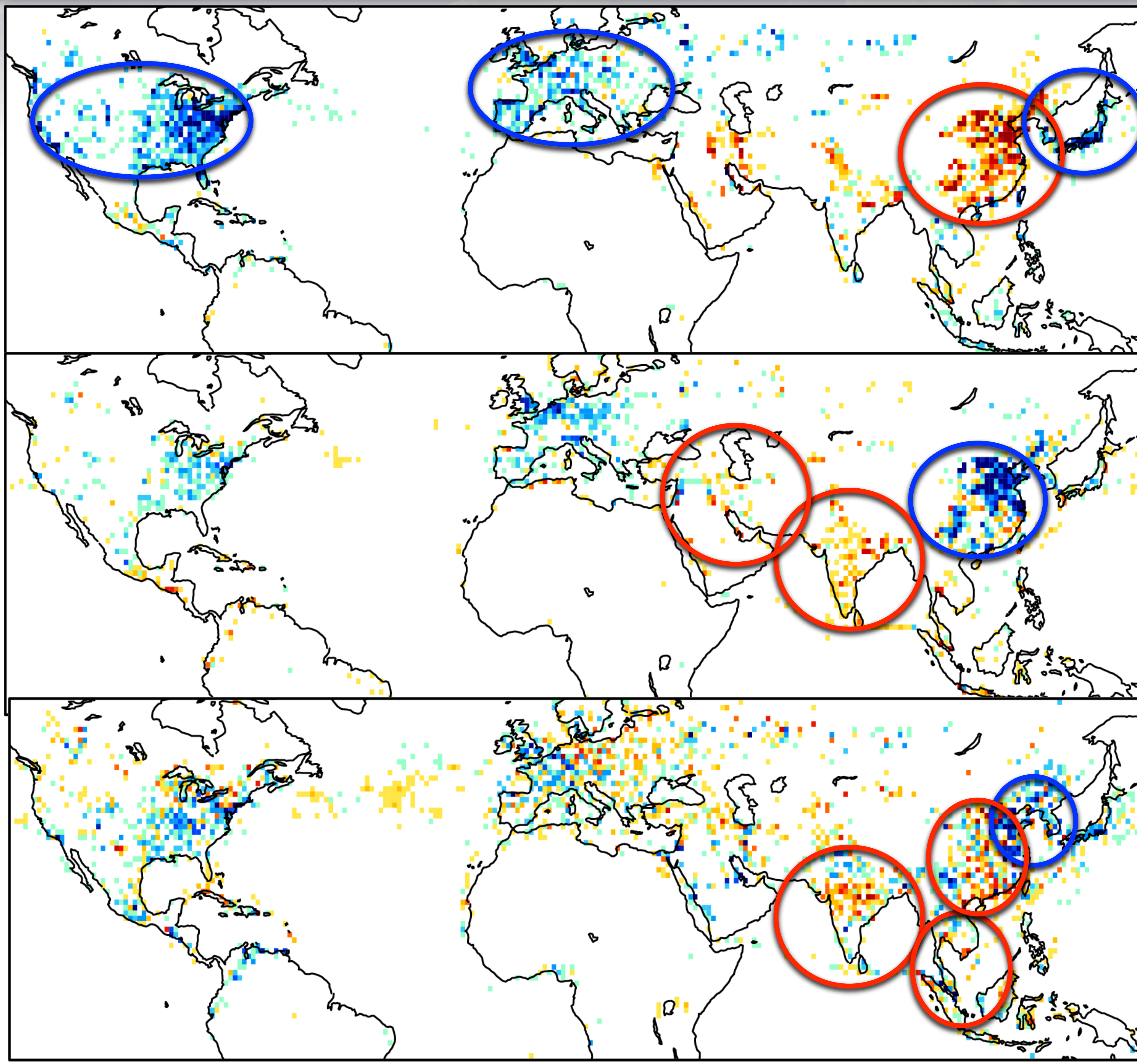


Global NOx emission trends (2005-2018)



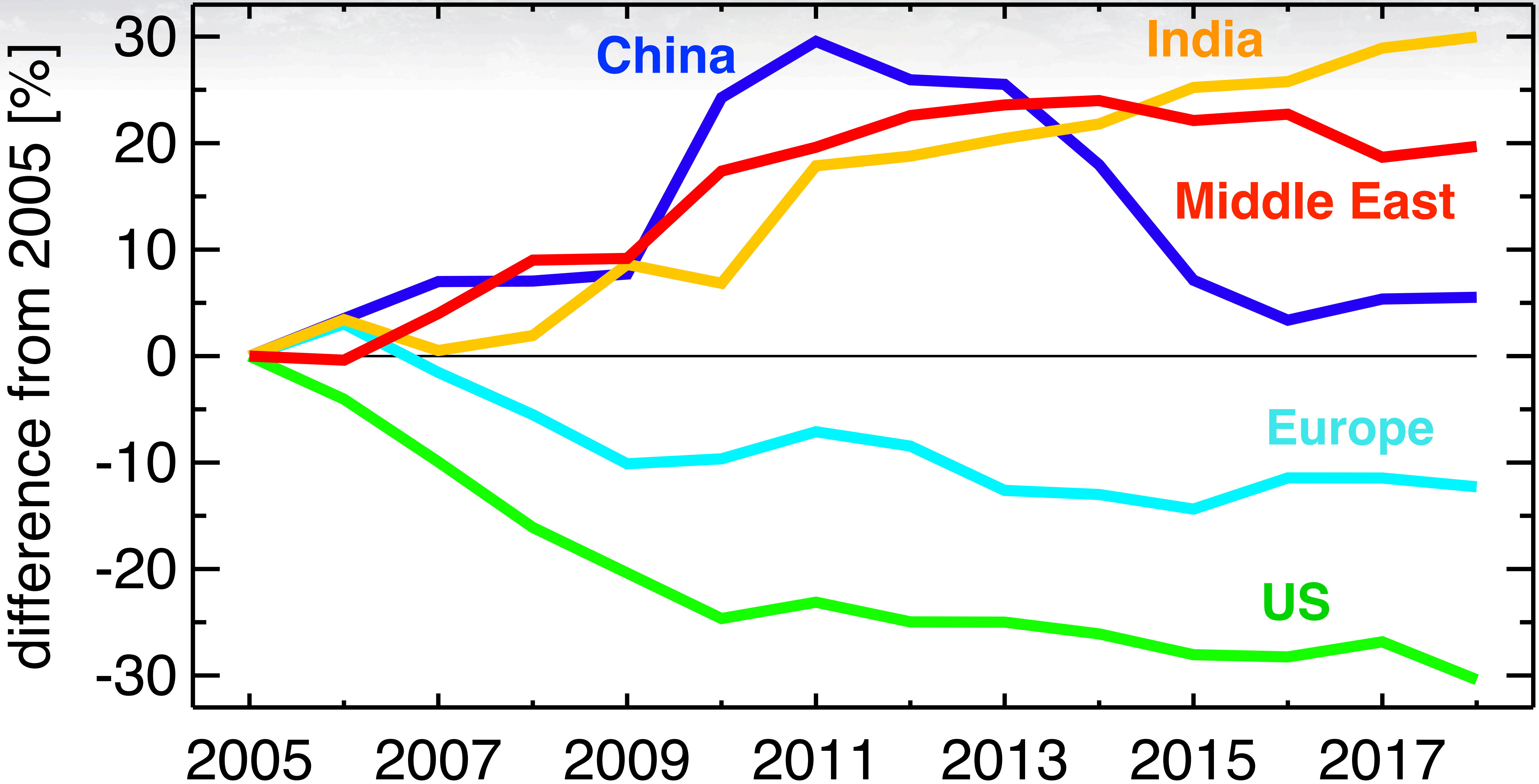
2005-2010

2010-2015

2015-2018

strong impacts on air quality and human health in developing countries

Global NOx emission trends (2005-2018)

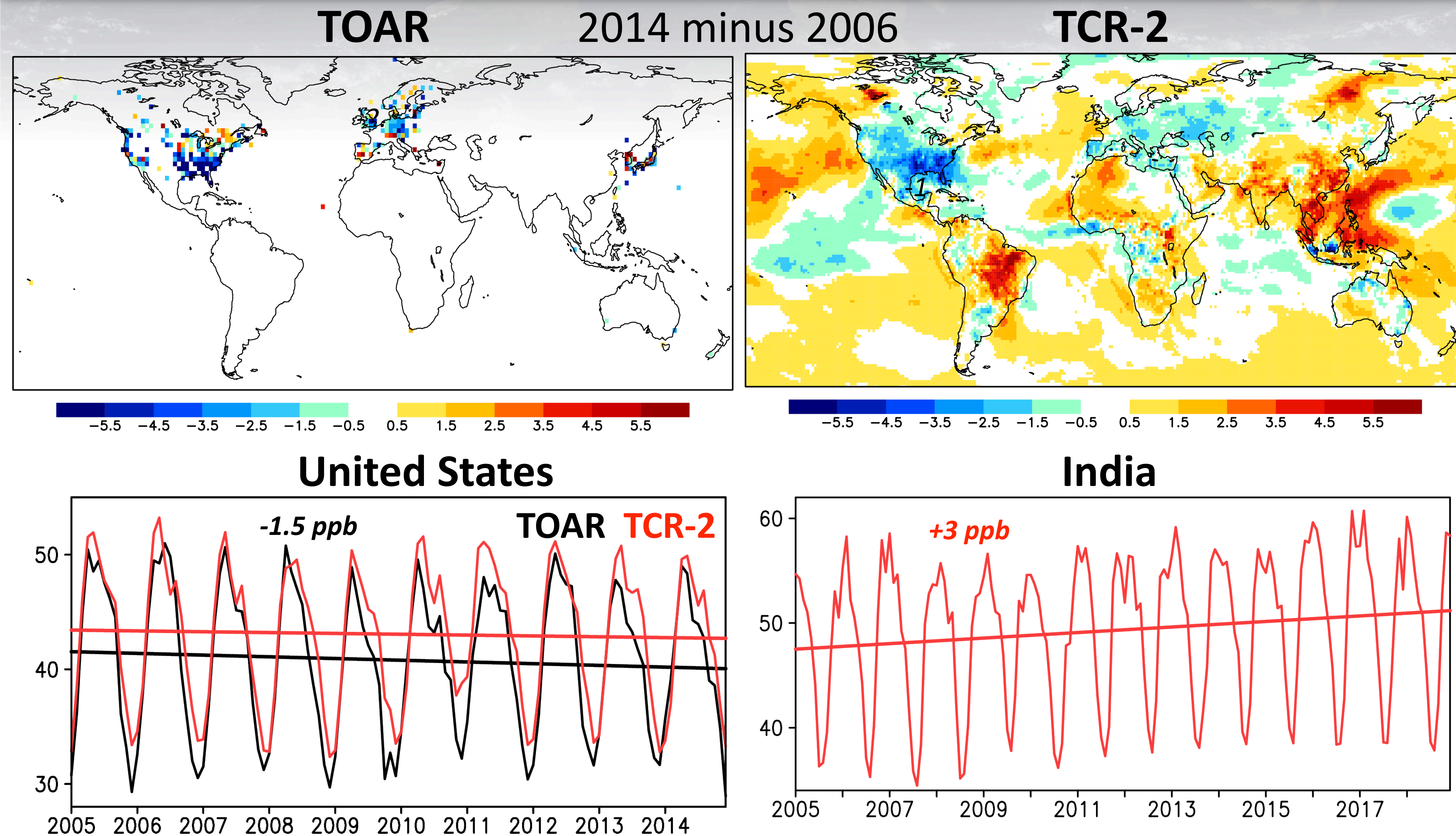


Global total emissions:

Almost constant during 2005-2018 (49.3±2.7TgN)

Miyazaki et al.,
to be submitted

Global surface ozone trends
(Annual average daily maximum 8-h ozone: ADM8h)



Chemical reanalyses provide useful information on exposure estimates and its attributions (mostly due to NOx emissions changes over polluted areas)

Change in mortality due to long-term ozone exposure

$$\Delta\text{Mort} = y_0(1 - \exp^{-\beta\Delta X})\text{Pop.}$$

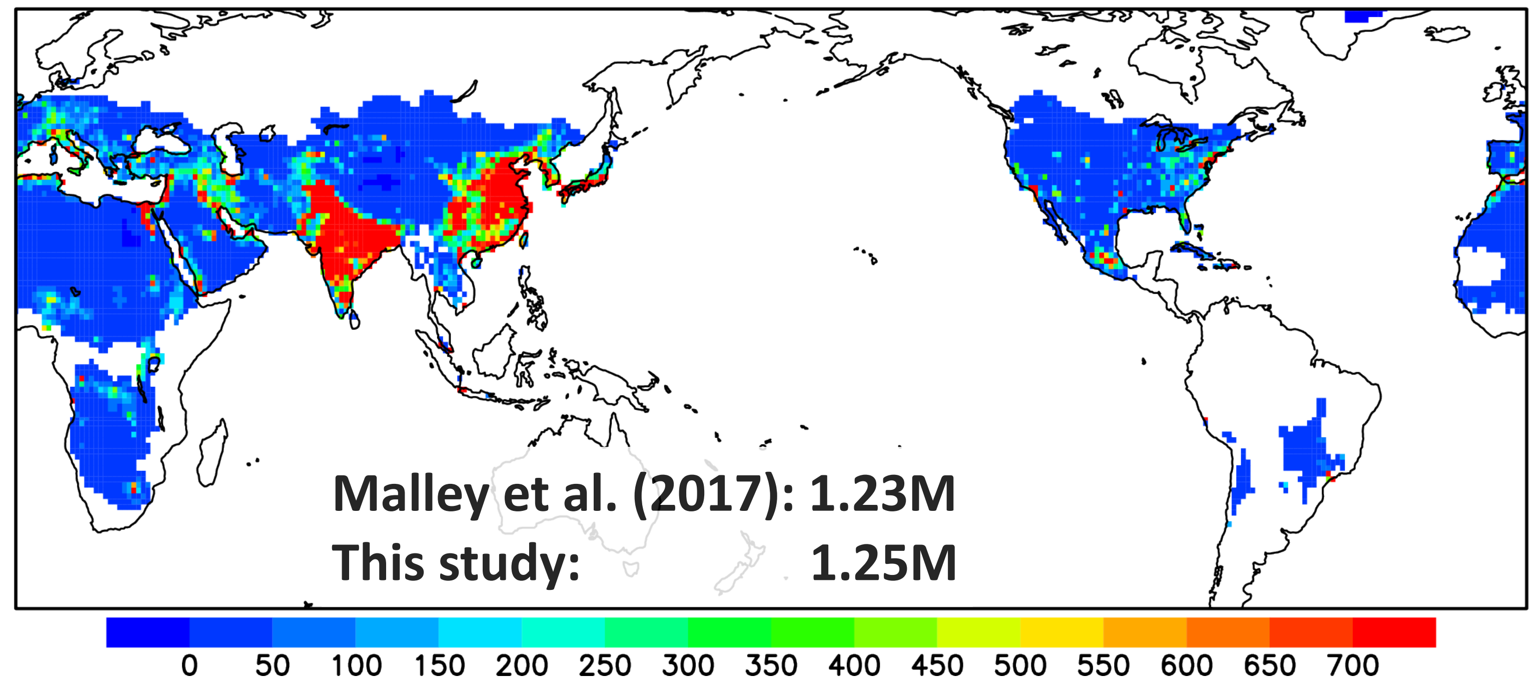
$$\text{HR} = \exp^{\beta\Delta Y}$$

$$\Delta X = \begin{cases} 0, & \text{if O3\_GC} \leq \text{LCC} \\ O3\_GC - LCC, & \text{if O3\_GC} > \text{LCC} \end{cases}$$

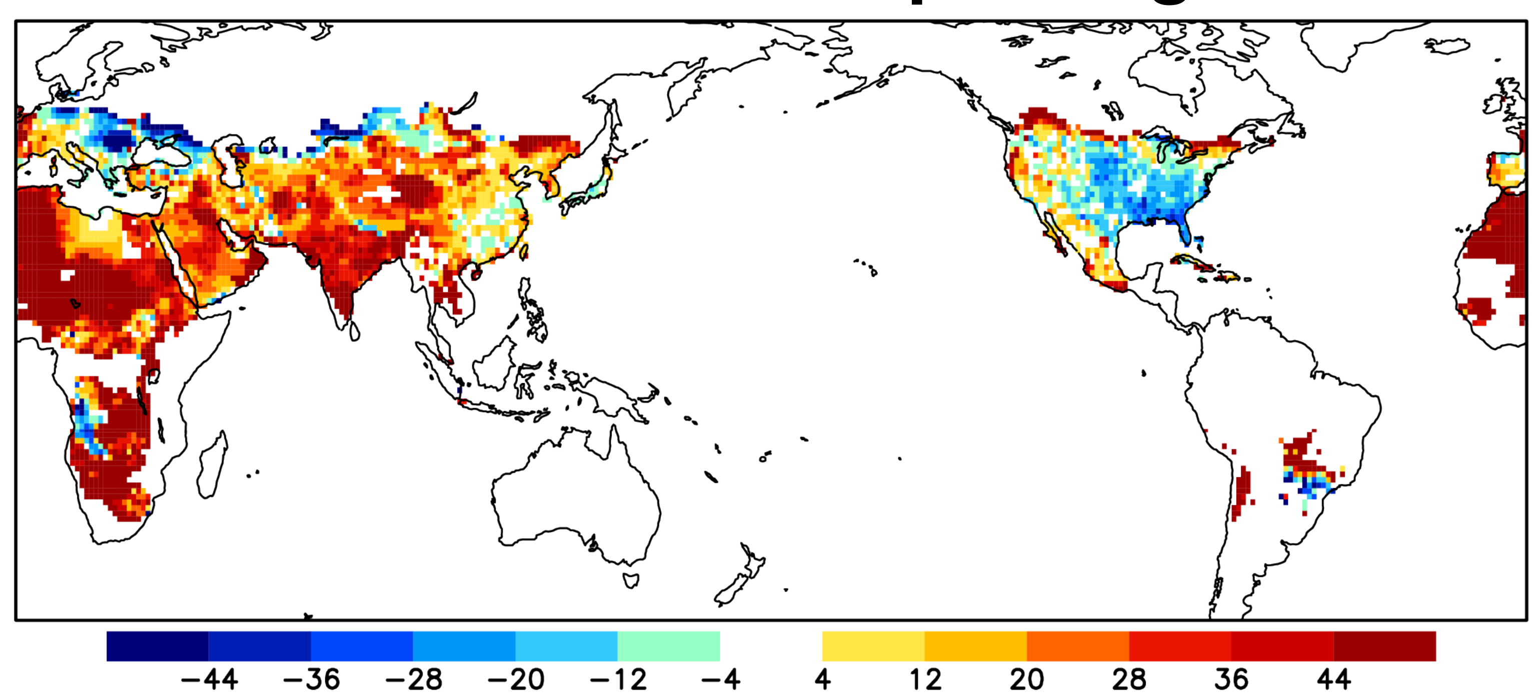
- *y_0: baseline mortality rate (800/100,000)*
- *Pop: exposed population (GWP v4)*
- *β: effect estimate (from the hazard ratio: HR))*
- *HR: 1.12 (Turner et al., 2016)*
- *LCC: 33.3 ppb*

	2005	2016	
Globe	1,002 K	1,248 K	25%↑
US	58 K	54 K	7% ↓
E China	256 K	280 K	9%↑
India	286 K	399 K	40%↑

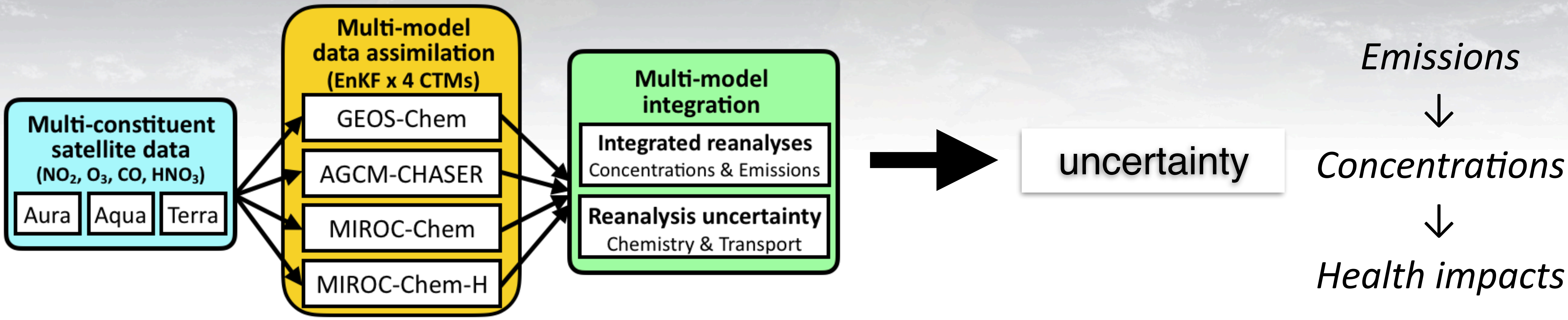
ΔMort in 2016 [number of deaths per 1°x1° grid]



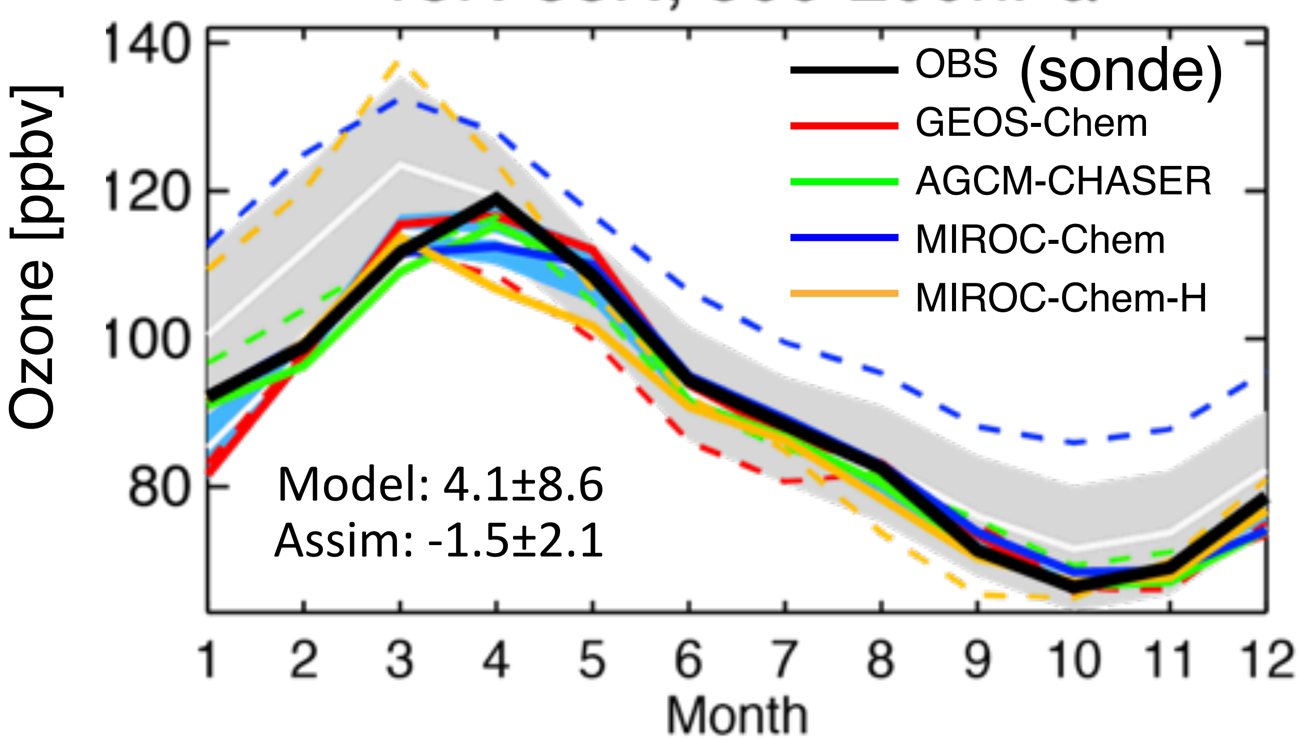
Difference between 2016 and 2005 [%] due to ΔX and Pop changes



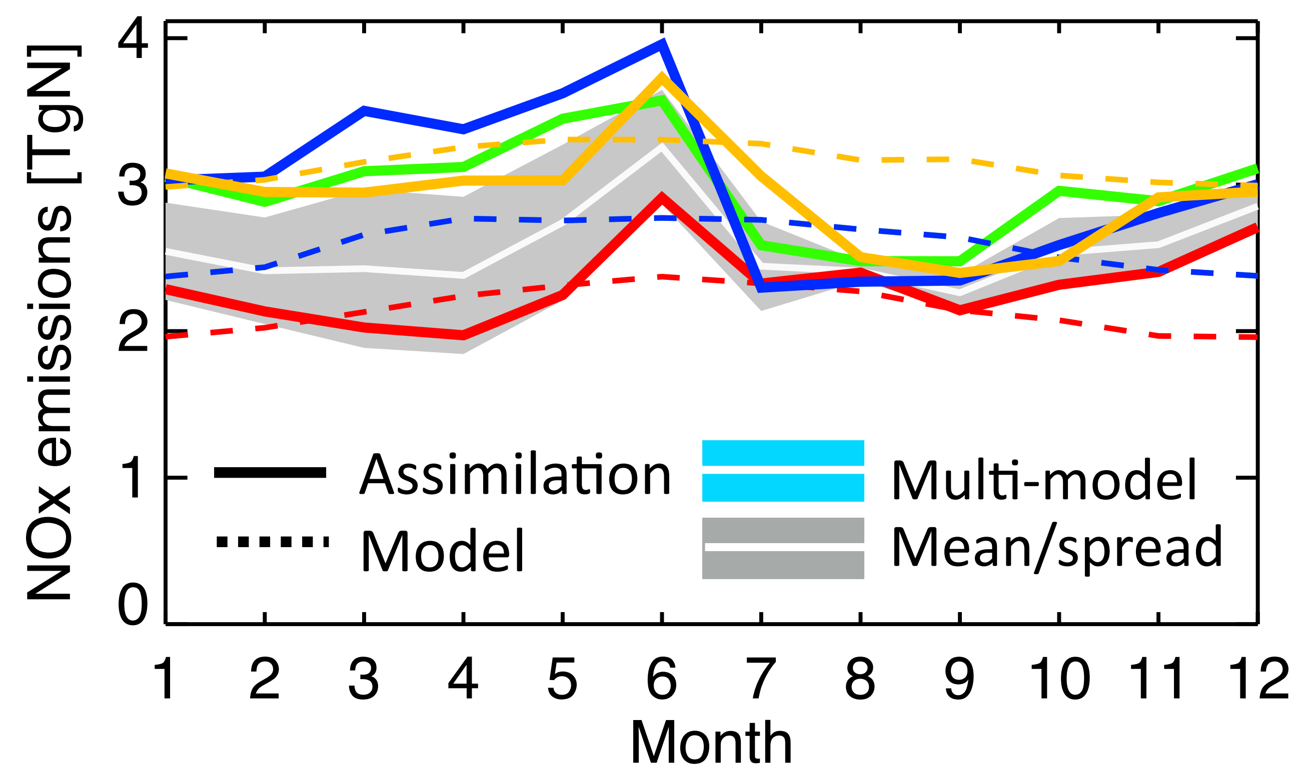
Uncertainty estimates using MOMO-Chem



O_3 15N-55N, 500-200hPa



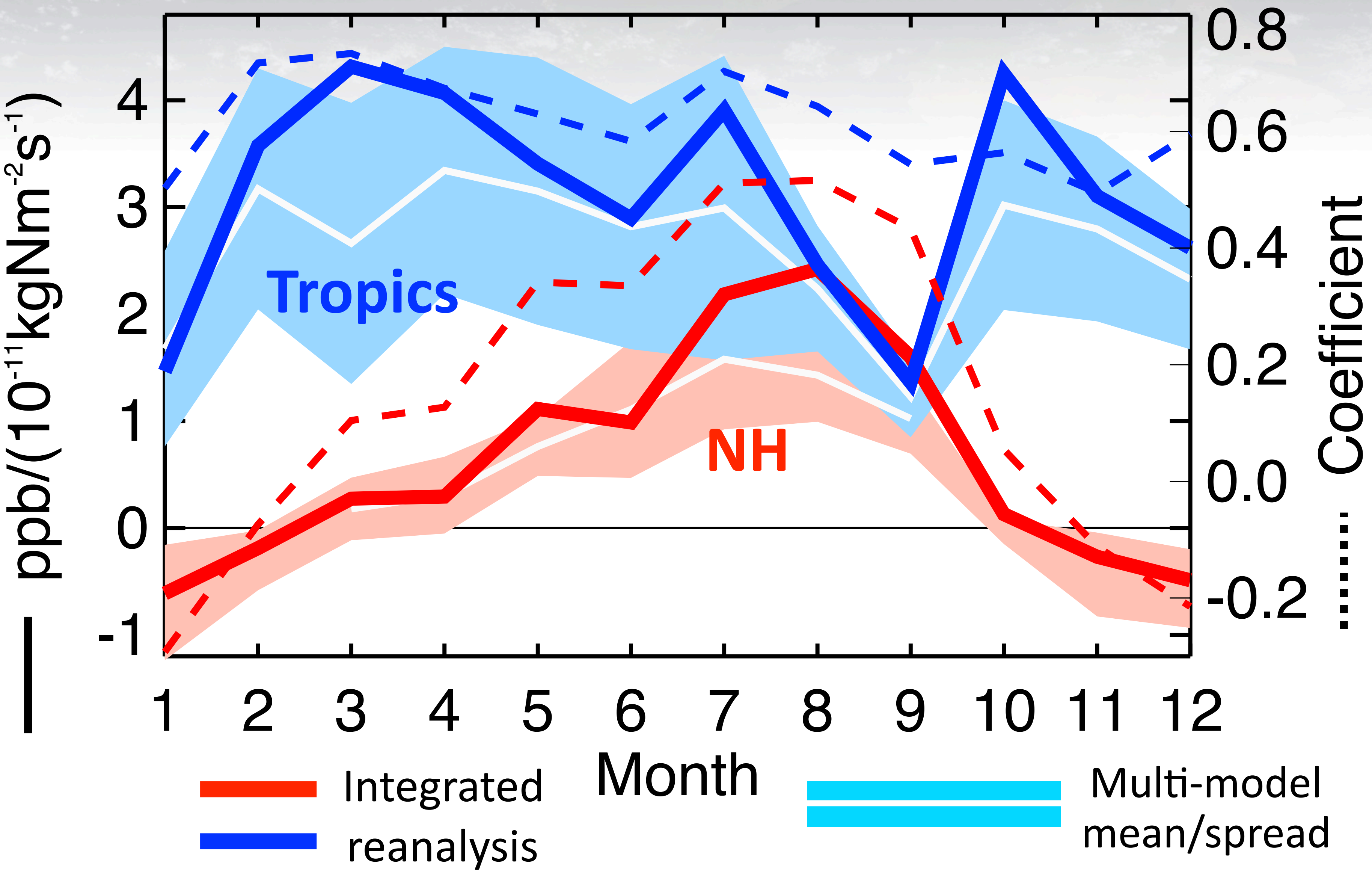
NOx emissions : India



- Harnessing the current observing system provides sufficient constraints to greatly reduce the influences of model errors and to provide the consistent ozone analysis

- Possible uncertainty ranges in the a posteriori emissions due to model errors: 13–31% for industrialized areas and 4–21% for BB areas.

Uncertainty estimates using MOMO-Chem



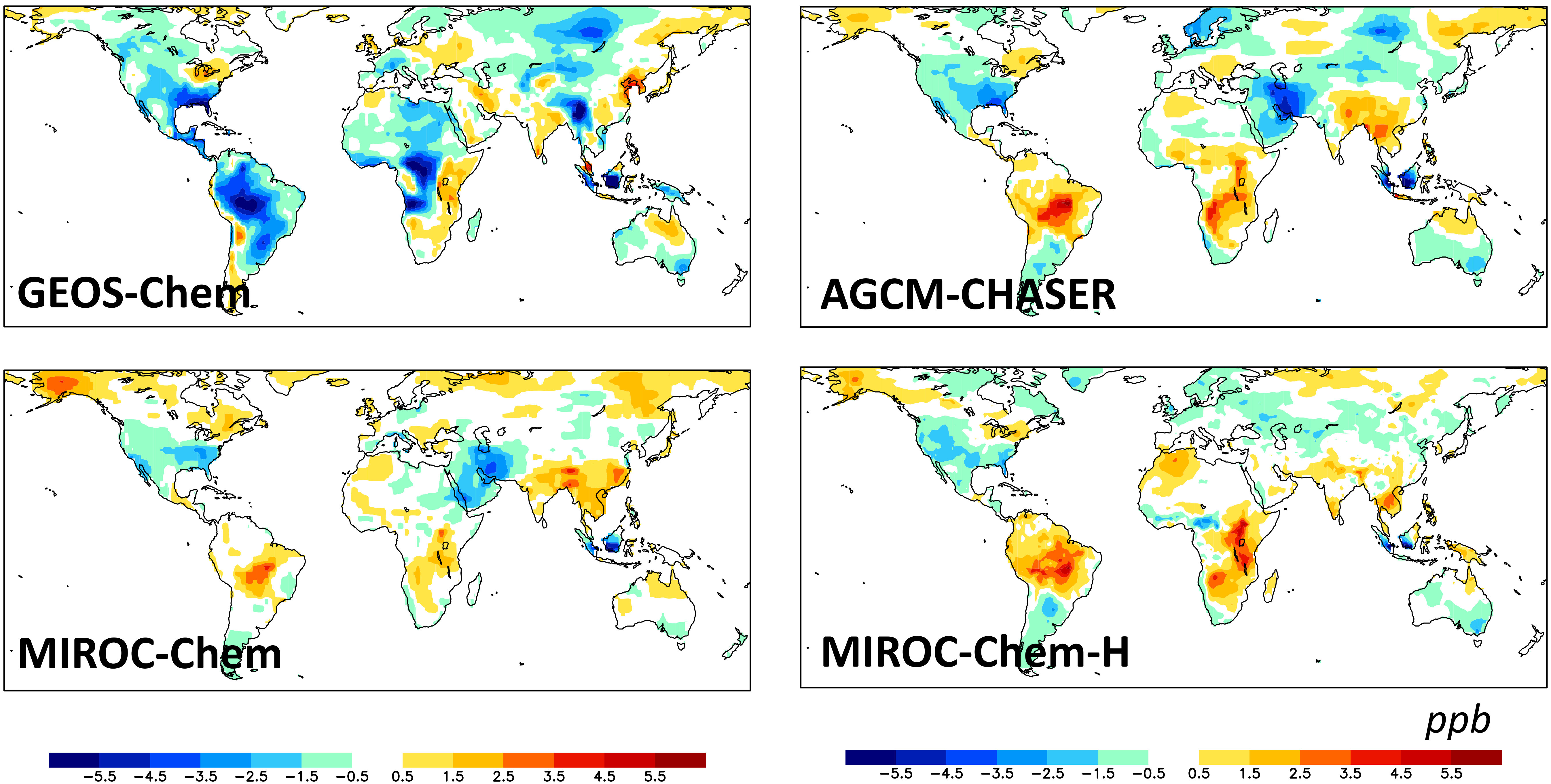
Surface ozone response to NOx emissions

The analysis increments were used to quantify model sensitivities related to chemistry and transport

- **TR > NH** : Latitudinal shifts in NOx emissions would increases global ozone.
- The sensitivity of surface ozone to NOx emissions varied by a factor of 2 among models, which would increase exposure estimate uncertainty.
- The observationally-constrained, multi-model integrated fields provide fundamentally different fast chemical processes than those in the individual models.

Uncertainty estimates using MOMO-Chem

MDA8 ozone trend (2016 minus 2006) : before assimilation



Unrealistic trends & large spreads among the models (2-10 ppb)

Uncertainty estimates using MOMO-Chem

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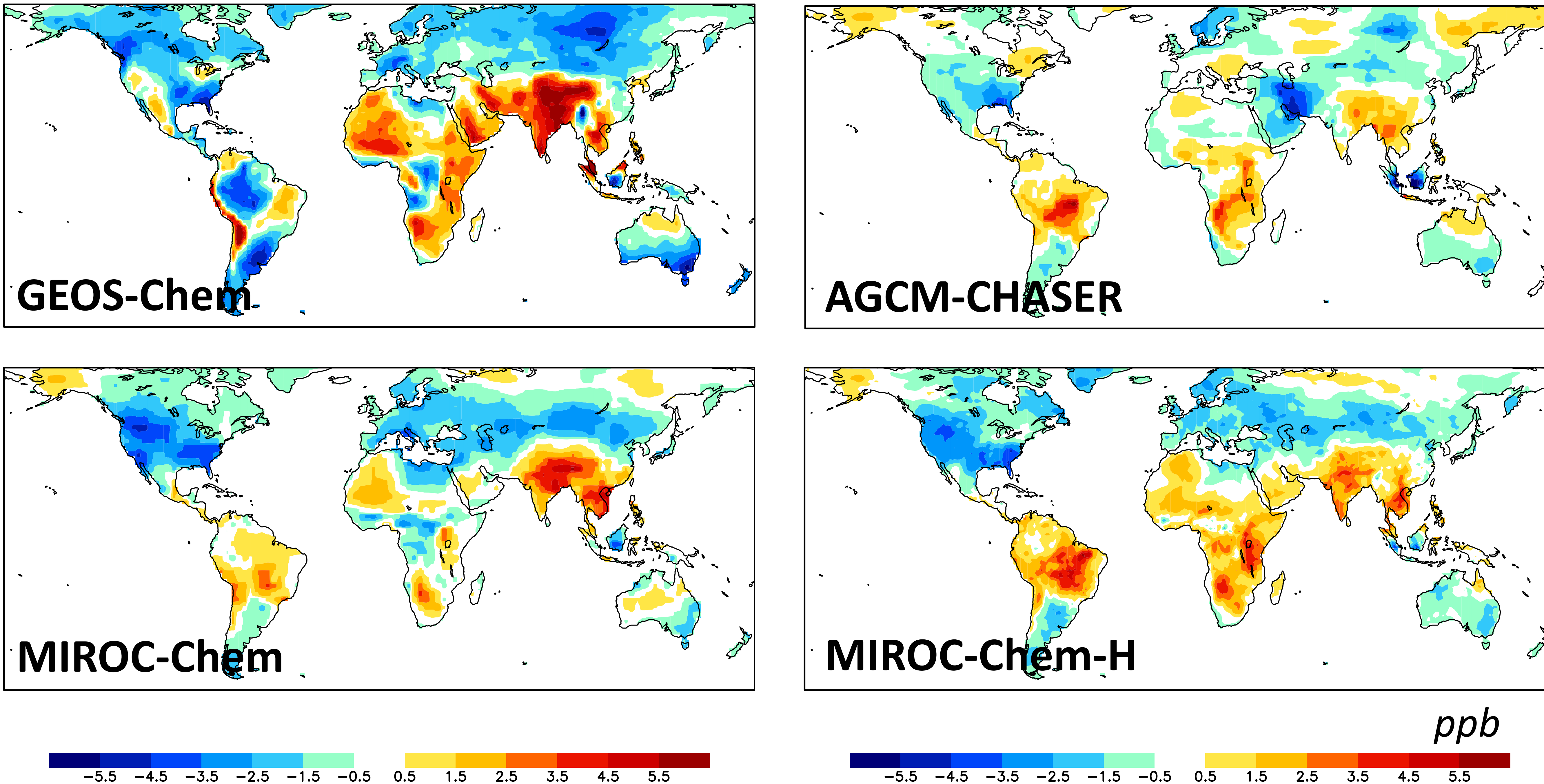
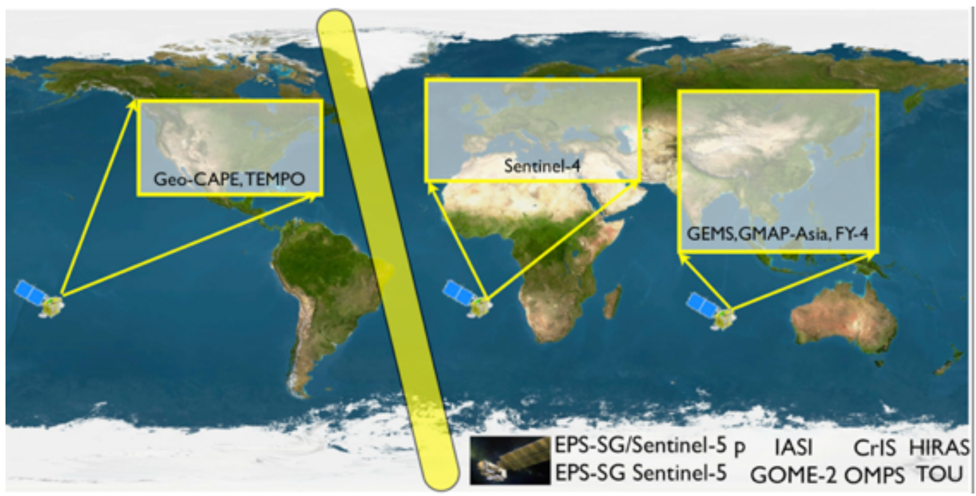


Multi-model spreads are reduced to 1-5 ppb

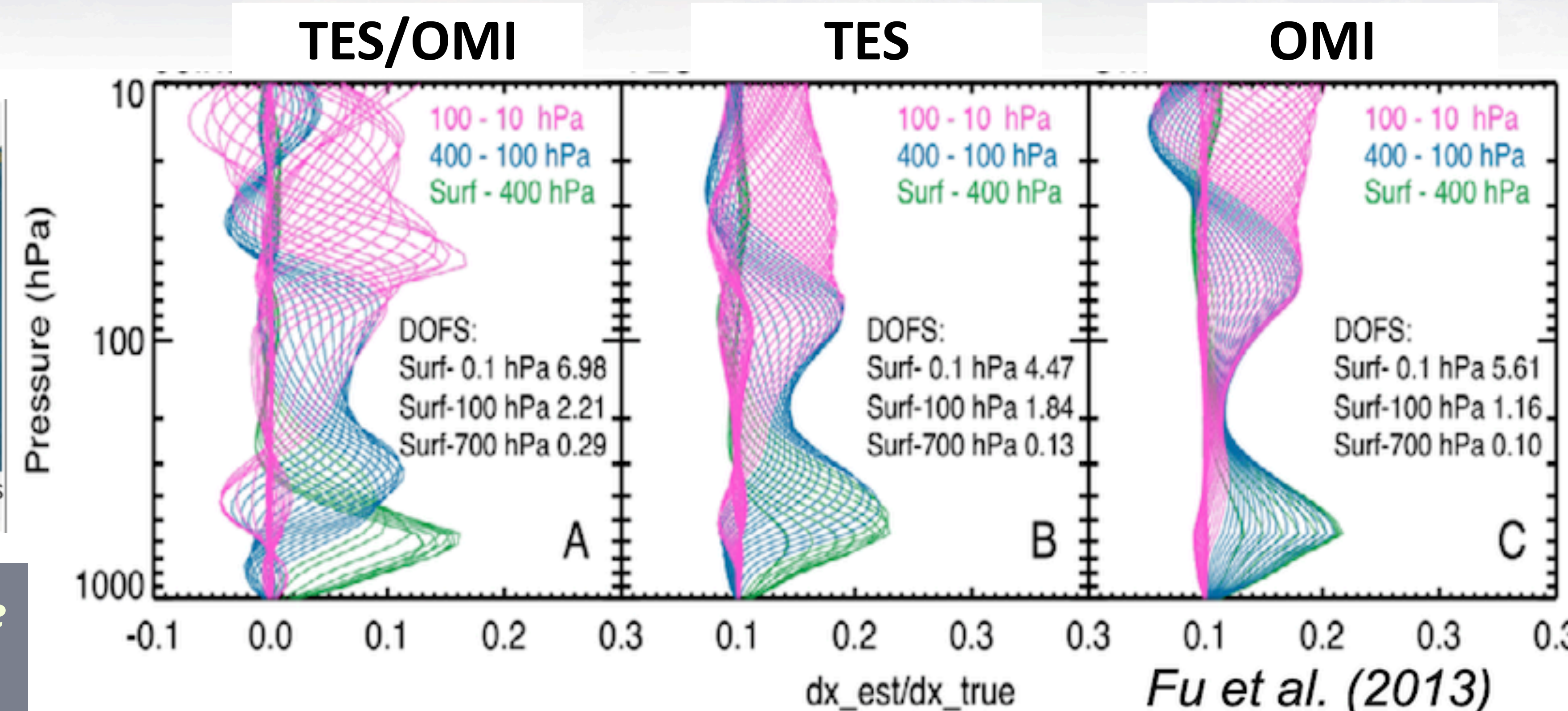
→ up to 30 % mortality uncertainty

Towards an Air Quality Constellation

Individual satellite measurements have provided an unparalleled source of global data but suffer from limited surface sensitivity for many key species

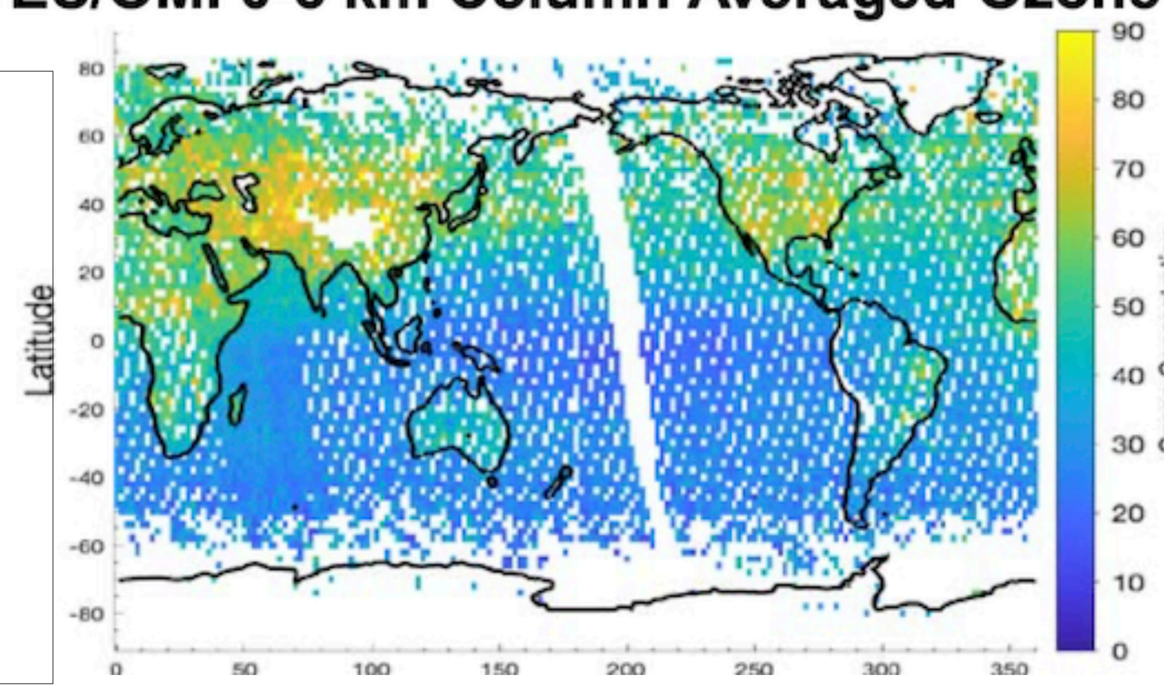


TES/OMI to infer global surface ozone
A53T-2932 poster by Nadia Colombi
(Friday afternoon)



Fu et al. (2013)

TES/OMI 0-3 km Column Averaged Ozone



How does the constellation improve health impact assessment?

- GEO sounders will provide an unprecedented number of composition observations at high resolution.
- LEO sounders (IASI, CrIS, S5p) provide the global picture and thread the GEO observations together.
- Multispectral retrievals provide improved vertical sensitivity.

Conclusions

- While the most recent reanalysis products (e.g., TCR-2 & CAMS) agree well each other, the discrepancy increased towards the surface due to differing chemical model, assimilation approaches, and observing system.

- The sensitivity of surface ozone to NOx emissions varied by a factor of 2 among models, which would increase the inter-reanalysis discrepancy and exposure estimate uncertainty.

- The multi-constituent and multi-model data assimilation framework provides observationally-constrained estimates of global air quality exposure (1.00M for 2005 and 1.25M for 2016) and its uncertainty (up to 30 %) for the past decade.

- Assimilating datasets from a new constellation of LEO sounders, GEO satellites, and multispectral retrievals would further enhance the potential of chemical reanalysis for observationally constrained global health impact assessment